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Flux Concentrations on Solar Dynamic Components Due to Mispointing

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FLUX CONCENTRATIONS ON SOLAR DYNAMIC COMPONENTS DUE TO MISPOINTING

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SUMMARY

Mispointing of the solar dynamic (SD) concentrator designed for use on Space Station Freedom (SSF) causes the optical axis of the concentrator to be nonparallel to the incoming rays from the Sun. This causes solar flux not to be focused into the aperture hole of the receiver and may position the flux on other SSF components. A Rocketdyne analysis has determined the thermal impact of off-axis radiation due to mispointing on elements of the SD module and photovoltaic (PV) arrays. The conclusion was that flux distributions on some of the radiator components, the two-axis gimbal rings, the truss, and the PV arrays could present problems. The OFFSET computer code was used at Lewis Research Center to further investigate these flux distributions incident on components. The Lewis study included distributions for a greater range of mispoint angles than the Rocketdyne study.

STATEMENT OF PROBLEM

This study was done to determine the flux concentrations incident on solar dynamic (SD) module components that could result from gross SD module mispointing during on-Sun operation. By examining these flux concentrations, potential safety issues can be addressed. A Rocketdyne analysis has been completed to determine the thermal impact to the SD module due to off-axis images (ref. 1). Gross mispointing is just one of four off-axis radiation possibilities. The other three are (1) reflections from the ocean and Earth albedo (light reflected back into space from the surface of the Earth), (2) radio frequency and point light sources, and (3) small off-axis angles.

Reflections from the ocean, infrared radiation, and Earth albedo have been studied; their concentrated effects are not expected to be significant, as reported by Jefferies in reference 2. Reflection of radio frequencies by the concentrator, although unexpected, need to be evaluated after the source and communications generating the frequencies have been defined. Ways to ensure that there is no interference can be developed when these radio frequencies are determined. Point light sources will be reflected and therefore are a concern, but only if they are located in the near vicinity of the concentrator, which is highly unlikely. Recent studies (ref. 2) show that concentrator mispoint angles up to 6° in both the alpha and beta direction (discussed in the section MODEL ASSESSMENT) will cause large portions of the flux to be incident on the receiver aperture plate, which is specially designed to withstand high heat flux. Flux intensity in other regions for larger mispoint angles is generally lower but had previously been evaluated on the basis of planes perpendicular to the parabolic axis or spheres centered on the concentrator, as in the Rocketdyne report.

The flux distributions resulting from a large range of mispoint angles were determined by OFFSET (ref. 3), a computer code that models the SD optical system. Flux distributions on the truss and the SD module components, which include the aperture plate, receiver, radiator, two-axis gimbal rings, and concentrator struts, can be generated using OFFSET.

The initial results are expressed in terms of flux incident for a range of alpha and beta mispoint angles. No attempt was made to analyze the thermal impact of the flux intensity on these components.

MODEL ASSESSMENT

The OFFSET code has been modified to investigate the flux incident on the components described in the preceding section. The flux distributions due to the Sun's rays being reflected by the solar concentrator were evaluated by OFFSET on predefined target planes. Figure 1 shows these planes and an outline of some SD module components. The SD module configuration used in this study has the aperture hole offset relative to the cavity centerline by 18 in. The two planes that contain the flux distribution are perpendicular to each other and will subsequently be referred to as the radiator and aperture planes.

Figure 2 defines the coordinate system for the SD module. The radiator plane (YZ-plane), as depicted in the figure, is parallel to the parabolic axis and bisects the concentrator. The aperture plane is perpendicular to the radiator plane and coplanar with the aperture plate. Projections onto the radiator and aperture planes of the truss, receiver, aperture plate, gimbal rings, concentrator, and radiator are also shown in figure 2. The flux distributions are generated on the radiator and aperture planes and therefore onto the components outlined on these planes. From the output plots, it can be determined which mispointing angles caused the flux not to be incident on the receiver aperture plate.

Alpha mispoint angles are caused by misalignment of only the concentrator with respect to the SD module, or misalignment of the whole SD module about an axis parallel to the X_{SD} axis, as shown in figure 2(a). A mispoint angle is measured from the concentrator optical axis to the incoming rays. Therefore, a negative mispoint angle occurs when the concentrator or SD module is rotated in the positive direction (assuming the polarity follows the right-hand rule), and a positive mispoint angle occurs when the concentrator is rotated in the negative direction (away from the truss). Similarly, referring to figure 2(b), positive and negative beta mispoint angles exist when the concentrator or SD module is misaligned about the Z_{SD} axis. In this case a negative mispoint angle corresponds to positive rotation of the SD module about the Z_{SD} axis, or an axis parallel to the Z_{SD} axis if only the concentrator is misaligned in the XZ_{SD} plane. Positive beta mispoint angles result from a negative rotation of the concentrator or SD module.

The flux distributions generated by OFFSET on the planes described are for the whole SD module, moving as an assembly, being misaligned because the code ignores correction for fine pointing of the concentrator. The same flux intensity will result for identical mispoint angles when only the concentrator is misaligned or, as in this study, when the whole SD module is misaligned, but the location of the flux distribution is not the same. When the whole SD module is misaligned, the flux distribution moves with the components and stays incident on them longer than if just the concentrator was misaligned. In this case, for similar mispoint angles, the flux is not incident on the exact same location because the concentrator moves with respect to the SD module.

Three different plot scales were chosen to plot the flux distribution on the SD components. This was to ensure that the components under study would be adequately displayed. When changing the plot scales, the size of the planes and the 10 000 elements that make up each plane also change. The smallest scale was chosen to determine the maximum flux distributions on the aperture plate, whereas a larger scale was used to encompass the radiator, truss, and receiver. Runs for identical mispoint angles with different scales should not be compared because the accuracy will vary among the plots because of the different element size used in calculations in OFFSET.

In all the OFFSET runs, both the slope and specular error were set equal to zero implying ideal facets which make up the solar concentrator and when properly focused reflect the Sun's rays into the receiver aperture hole. Thus the peak flux values generated in this study are conservatively higher than actual.

The blockage of flux distribution by the receiver and attached 85 in.-diameter plate was included in this preliminary analysis of flux distributions. Blockage that may occur as a result of the flux incident on the gimbal rings was not included.

OFFSET was further modified for this study to determine the peak flux value on the outside of the receiver due to mispointing. Plots were generated to show the flux distribution incident on the outside of the receiver. These plots were depicted in two dimensions by unwrapping the outer layer of the receiver and laying it flat.

RESULTS

Both alpha and beta angle mispoints can cause the solar flux not to be focused into the aperture hole or on the surrounding shield but rather may position the flux on other SSF components. The results created in this study are for alpha angle mispoints ranging from -20° to 20° and beta angle mispoints ranging from -15° to 15° in 5° increments. Smaller alpha and beta mispoint cases were run for angles ranging from -5° to 5° in 1° increments and then at 2° increments up to $\pm 12^\circ$ to determine the flux on the aperture plate, gimbal rings, and concentrator struts. At small mispoint angles the flux is extremely concentrated and requires that the aperture plate be tolerant of very high heat flux. Mispointing will disperse the flux, thus allowing tolerable flux on the aperture plate but possibly causing spilloff onto other components under study. These results can be used to find areas on the aperture shield that can withstand the flux or other areas that do not contain any components. The areas that contain no components are "safe haven zones." If problems arise with the pointing system, the concentrator can be aimed at one of these zones to minimize any damaging effects to the SD components.

The flux distribution results taken from the radiator and aperture planes are summarized in tables I to VI. The case for no pointing error (alpha and beta both equal to zero) is shown in figures 3 and 4 for the radiator and aperture planes, respectively. Most of the flux is shown to pass through the aperture hole, but some flux is incident on the surrounding area of the aperture plate.

Truss

The greatest flux intensity incident on the truss, approaching 1.4 W/cm^2 (10 Suns), occurred at 5° beta mispoint and 10° alpha mispoint. This is shown in figure 5. Table I lists a summary of the maximum incident solar flux on the truss occurring for the range of mispoint angles studied. The data in table I and all the tables showing the flux intensity incident on the various components is nearly symmetric with respect to beta mispoint angles. This is because the concentrator is symmetric about the YZ plane and beta mispointing moves the flux on either side of this plane.

Aperture Plate

As stated earlier, recent studies show that concentrator mispoint angles up to 6° in both the alpha and beta direction will cause large portions of the flux to be incident on the receiver aperture plate. In this study the actual mispointing angles that bound the flux on the aperture were found. The mispoint angles which place some flux on the aperture plate ranged from 4.5° to −8.5° in the alpha direction with no beta mispointing. The range was not symmetric about 0° because the aperture hole was offset relative to the cavity centerline by 18 in. The beta mispoint angles were symmetric about 0° and were found to be totally off the aperture plate at ±8° with no alpha mispointing. The greatest flux intensity incident on the aperture plate, approaching 1154 W/cm^2, occurred at 0° beta mispoint and −1° alpha mispoint. Table II lists a summary of the flux incident on the aperture plate for the range of mispoint angles studied.

Receiver

The mispoint angles which placed the greatest flux intensity incident on the receiver, approximately 76 W/cm^2 (555 Suns), occurred at 0° beta mispoint and 5° alpha mispoint, as shown on the unwrapped receiver plot in figure 6. The data from table III indicate that the greatest flux on the side of the receiver occurred at alpha mispointing angles from 0° to 15°, with corresponding beta mispoint angles ranging between 10° to −10°.

Radiator

The mispoint angles which placed the greatest flux intensity incident on the radiator, approximately 8 W/cm^2 (58 Suns), occurred at 5° beta mispoint and −15° alpha mispoint, as shown in figure 7. The data from table IV indicate that the greatest flux incident on the radiator was at alpha mispoint angles from 5° to −20° with corresponding beta mispoint angles ranging from 10° to −10°.

Gimbal Rings

In the baseline SD pointing system, the two-axis gimbal rings that fine point the concentrator are located in the aperture plane. From the peak flux values listed in table V, the maximum flux incident on the gimbal rings would be roughly 142 W/cm^2 (1039 Suns) occurring at 4° alpha mispoint and 2° beta mispoint. (See fig. 8.)

Concentrator Struts

Attached to the two-axis gimbal configuration are six struts that connect from the concentrator to the outer gimbal ring at three points, all of which lie in the aperture plane. Table VI lists the results of flux distributions in the vicinity of these points and indicates a maximum incident flux of 69 W/cm^2 occurring at 8° beta mispoint and 2° alpha mispoint. (See fig. 9.)

DISCUSSION

The analyses show that some mispointing angles caused large flux distributions to be incident on the components.

Truss

The results show that only one truss bay had flux incident on it. This suggests that possible shielding of the bay could alleviate any problems encountered during these mispoint scenarios.

Aperture plate

The primary purpose of the aperture plate is to protect the receiver from high fluxes and to prevent heat loss from the receiver cavity. Initial results (ref. 4) show that the aperture plate is capable of tolerating the high fluxes and the resulting thermal loading due to mispointing.

Receiver

The SD module design had a parasitic load radiator (PLR) attached to the receiver in the radiator plane, between the truss and the receiver. Plots of the flux distribution on the outside of the receiver show that it may be beneficial to move the PLR or build in extra protection measures for it.

Blockage of the flux distribution incident on the aperture plate was included in the OFFSET code. Depending on the fine-pointing method that is chosen, there may be gimbal rings around the aperture plate that block some of the flux that would otherwise be incident on the outside of the reciever. Flux distribution blockage by the gimbal rings were not included in the OFFSET code. The flux on the sidewall will be lower than 76 W/cm^2 if gimbal rings around the aperture plate are used for concentrator fine pointing.

Radiator

When analyzing the effects of the flux concentrations on the radiator, all the components which make up the radiator should be included because of the different material properties. Also, impact on the SD module from higher coolant temperatures should be determined.

Concentrator Gimbal Rings and Struts

The concentrator struts are made out of the same material as the truss members. Reviewing the thermal analysis on the truss structure from the Rocketdyne study indicates that the concentrator struts will not be able to withstand the temperatures generated at those mispoint angles on table VI that show a flux greater than 3.0 W/cm^2.

Design efforts are proceeding to a beta fine-pointing system which eliminates the two-axis gimbal rings. Because of this, the six struts that had previously been connected to the two-axis gimbal rings to support the concentrator may be positioned at a greater distance away from the receiver aperture plate, and therefore a lower incident flux may be placed on them.

The probability for mispointing scenarios are low because of the redundancy of the pointing system. Should either the alpha or beta gimbal become inoperable, the other gimbal could be used to detrack the concentrator to a desired location. Furthermore, a beta fine-pointing system will have a means of correctively fine-pointing the alpha axis $\pm 15°$ about the center of the receiver. Examining the tables reveals that "safe haven zones" exist at beta mispoint angles greater than $\pm 20°$ with any combination of alpha mispoint angles. Additionally, the results can be used to observe areas where the flux is incident in smaller magnitudes and imposes no damaging effects, thus ensuring safe module operation.

CONCLUDING REMARKS

Although mispointing scenarios are numerous, this preliminary analysis looks at a small range of alpha and beta mispoint angles and the resulting flux on specified components in just two planes. The OFFSET computer code was modified to give the exact location of the flux distribution with respect to the SD module components. With these modifications, credible mispoint occurrences can be analyzed, specifically the dispersion of the flux over time due to its movement on the specific components. This data would then be used to determine the impact on the SD components due to the flux concentrations. Possible ways to ensure safe operation can then be developed. One way could be controlled mispointing of the SD module and its associated potentially hazardous flux distributions into the "safe haven zones," as discussed here. Solar dynamic development as part of the Space Station Freedom program was discontinued in March 1991.

REFERENCES

1. Solar Dynamic Off-Axis Images Thermal Impacts. Internal Report EID–00695. Rocketdyne, Canoga Park, CA, Oct. 1990.

2. Jefferies, K.S.: Concentration of Off-Axis Radiation for Space Power. NASA TM–102052, 1989.

3. Jefferies, K.S.: Ray Tracing Optical Analysis of Offset Solar Collector for Space Station Solar Dynamic System. NASA TM–100853, 1988.

4. Quinn, R.D.; Kerslake T.W.: Solar Dynamic Modules for Space Station Freedom: The Relationship Between Fine-Pointing Control and Thermal Loading of the Aperture Plate. NASA TM–104498, 1992.

TABLE I.—PEAK FLUX ON TRUSS DUE TO MISPOINTING

Beta mispoint angle, deg	Flux intensity, W/cm^2								
	Alpha mispoint angle, deg								
	−20	−15	−0	−5	0	5	10	15	20
−15	---	---	---	-----	-----	-----	------	-----	-----
−10	---	---	---	-----	0.3	0.7	0.5	-----	-----
−5	---	---	---	0.2	.2	.7	1	1.1	0.7
0	---	---	---	-----	-----	0	0	.1	.2
5	---	---	---	.2	.2	.7	1.4	1	.7
10	---	---	---	-----	.3	.7	.5	-----	-----
15	---	---	---	-----	-----	-----	------	-----	-----

TABLE II.—PEAK FLUX ON APERTURE PLATE DUE TO MISPOINTING

Beta mispoint angle, deg	Flux intensity, W/cm^2										
	Alpha mispoint angle, deg										
	−5	−4	−3	−2	−1	0	1	2	3	4	5
−5	101	135	155	163	180	197	145	7.9	-----	-----	---
−4	120	146	191	209	233	245	243	140	-----	-----	---
−3	135	166	223	287	322	332	312	199	8.6	-----	---
−2	137	198	285	422	494	476	365	253	80	-----	---
−1	139	205	355	613	910	872	416	318	171	0.2	---
0	140	216	376	706	1154	10.2	454	310	146	.3	---
1	145	214	349	598	902	893	420	317	192	.2	---
2	139	200	289	415	493	511	379	245	94	-----	---
3	128	167	227	287	329	351	304	199	19	-----	---
4	117	154	187	209	236	259	241	148	-----	-----	---
5	97	132	147	163	180	195	154	8.9	-----	-----	---

TABLE III.—PEAK FLUX ON RECEIVER DUE TO MISPOINTING

Beta mispoint angle, deg	Flux intensity, W/cm^2								
	Alpha mispoint angle, deg								
	−20	−15	−10	−5	0	5	10	15	20
−15	---	---	---	-----	---	-----	-----	-----	-----
−10	---	---	---	-----	---	-----	-----	-----	-----
−5	---	---	---	1.9	---	29.9	9	-----	-----
0	---	---	---	-----	---	76.1	15.6	4.7	-----
5	---	---	---	10.3	---	36.1	9.2	-----	-----
10	---	---	---	-----	---	-----	-----	-----	-----
15	---	---	---	-----	---	-----	-----	-----	-----

TABLE IV.—PEAK FLUX ON RADIATOR DUE TO MISPOINTING

Beta mispoint angle, deg	Flux intensity, W/cm^2								
	Alpha mispoint angle, deg								
	−20	−15	−10	−5	0	5	10	15	20
−15	---	1.1	1	0.7	0.5	-----	-----	-----	---
−10	4.5	3.6	2.8	2.4	.9	0.5	0.2	-----	---
−5	6.3	7.8	2.7	.4	-----	-----	-----	0.2	---
0	5.1	.2	.1	.1	-----	-----	-----	0	---
5	6.3	7.8	2	.4	-----	-----	-----	.2	---
10	4.6	3.5	2.9	2.3	1	.5	.2	-----	---
15	---	1.1	1	.7	.4	-----	-----	-----	---

TABLE V.—PEAK FLUX ON GIMBAL RINGS DUE TO MISPOINTING

Beta mispoint angle, deg	Flux intensity, W/cm^2												
	Alpha mispoint angle, deg												
	−12	−10	−8	−6	−4	−2	0	2	4	6	8	10	12
−12	---	-----	------	-----	-----	------	------	------	------	-----	----	---	---
−10	---	-----	------	0	62.2	61	57.1	71.1	------	-----	----	---	---
−8	---	-----	0.7	59.2	74	80.4	100	94.8	57.7	-----	----	---	---
−6	---	-----	52.7	74.3	74.8	90.2	17.5	113	70.2	13.1	----	---	---
−4	---	6.6	55.8	60.9	40.5	99.4	34.6	67.4	120	72.5	----	---	---
−2	---	31.4	72.6	37	.9	------	------	8	141	66.4	----	---	---
0	---	28.5	69.9	21.7	1.5	------	------	------	107	59	0.2	---	---
2	---	38.2	70.2	33.4	1.4	------	------	8.4	142	65.1	----	---	---
4	---	6.3	54.9	62.5	46	22.4	34.1	55.4	120	69.2	----	---	---
6	---	-----	53.3	78.8	72.6	63	58.8	114	66	16.1	----	---	---
8	---	-----	1	60.9	75.6	77.1	99	97.4	60.4	-----	----	---	---
10	---	-----	------	.1	61.9	60.9	64.1	78.3	-----	-----	----	---	---
12	---	-----	------	-----	-----	------	-----	-----	-----	-----	----	----	---

TABLE VI.—PEAK FLUX ON CONCENTRATOR STRUTS DUE TO MISPOINTING

Beta mispoint angle, deg	Flux intensity, W/cm^2												
	Alpha mispoint angle, deg												
	−12	−10	−8	−6	−4	−2	0	2	4	6	8	10	12
−12	---	-----	-----	-----	---	---	-----	-----	-----	---	---	---	---
−10	---	-----	-----	-----	---	---	-----	14.7	-----	---	---	---	---
−8	---	-----	-----	-----	---	---	-----	66.9	-----	---	---	---	---
−6	---	-----	-----	-----	---	---	54	18.8	12.5	---	---	---	---
−4	---	-----	10.6	1.2	---	---	-----	-----	22.4	---	---	---	---
−2	---	10.6	2.3	1.8	---	---	-----	-----	-----	---	---	---	---
0	---	28.6	21.4	2.4	---	---	-----	-----	-----	---	-----	---	---
2	---	10.6	2.9	.2	---	---	-----	-----	-----	---	---	---	---
4	---	-----	14.3	.8	---	---	-----	-----	23.3	---	---	---	---
6	---	-----	-----	-----	---	---	48.3	16.9	25.6	---	---	---	---
8	---	-----	-----	-----	---	---	-----	68.9	-----	---	---	---	---
10	---	-----	-----	-----	---	---	-----	49.6	-----	---	---	---	---
12	---	-----	-----	-----	---	---	-----	-----	-----	---	---	---	---

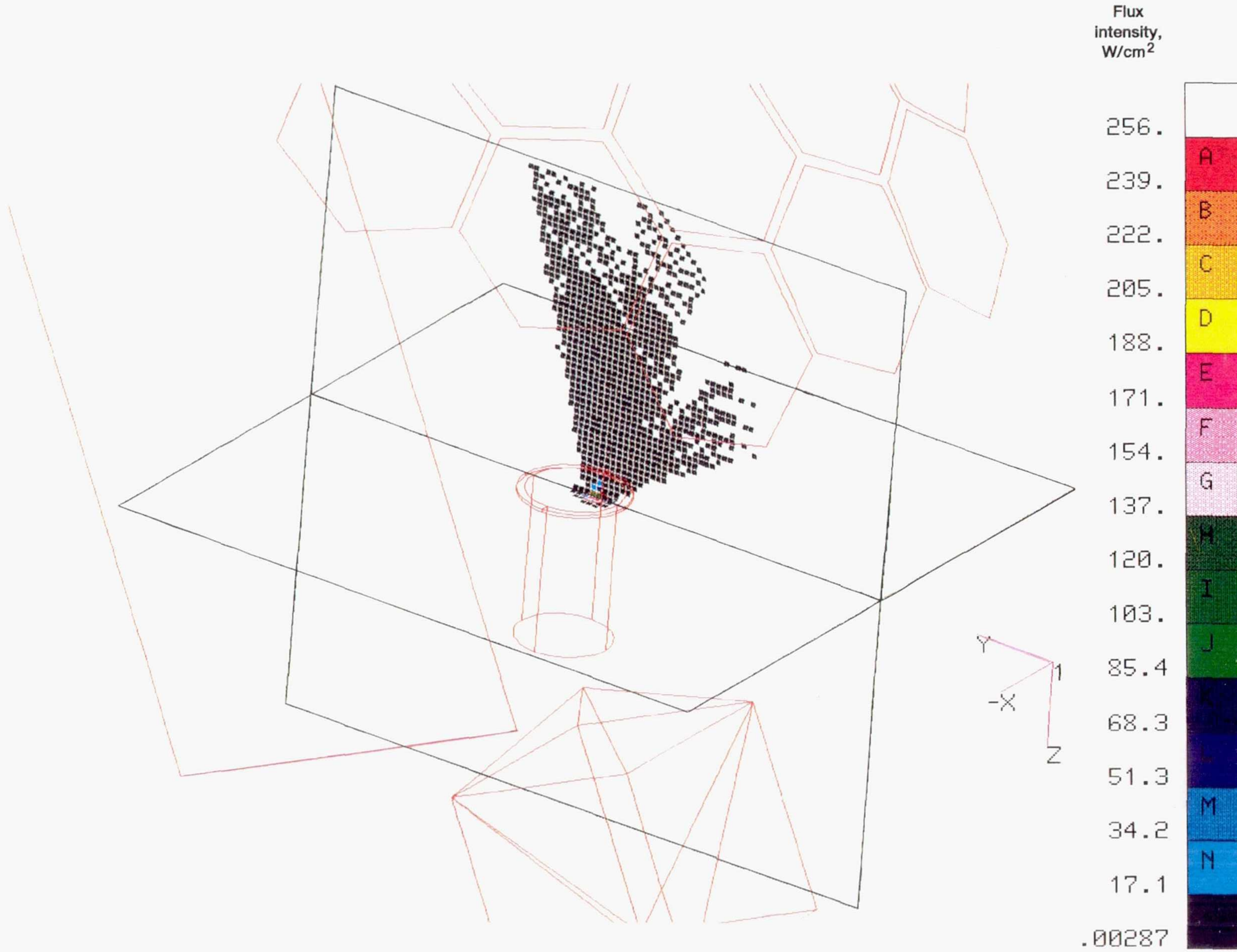

Figure 1.—Flux distribution on 500-by 500-in. ^{2} planes (alpha and beta mispoint angles, 0°).

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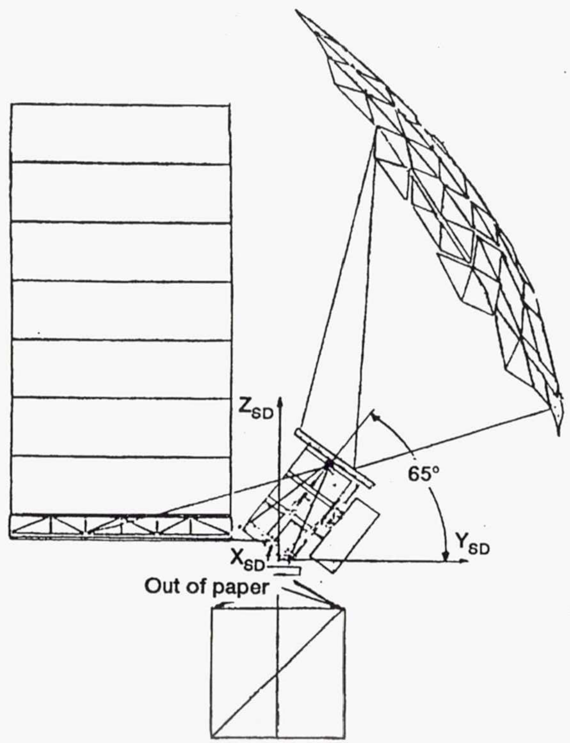
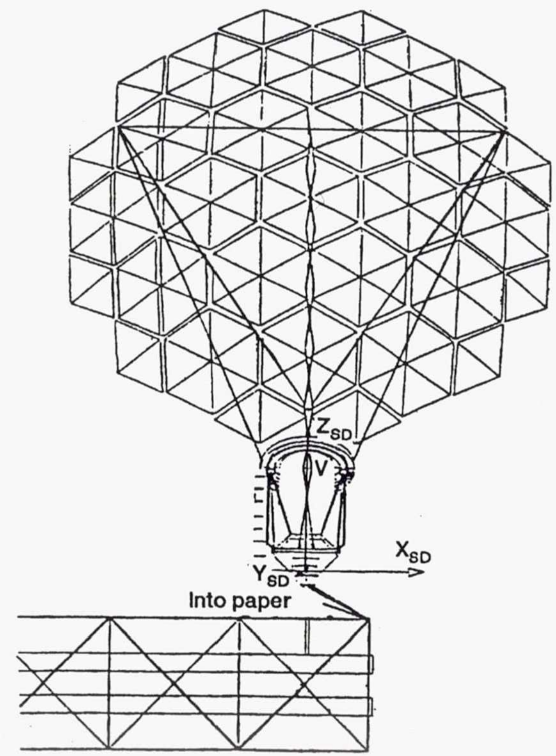


(a) Alpha mispoint angle.



(b) Beta mispoint angle.

Figure 2.—Solar dynamic coordinate system.

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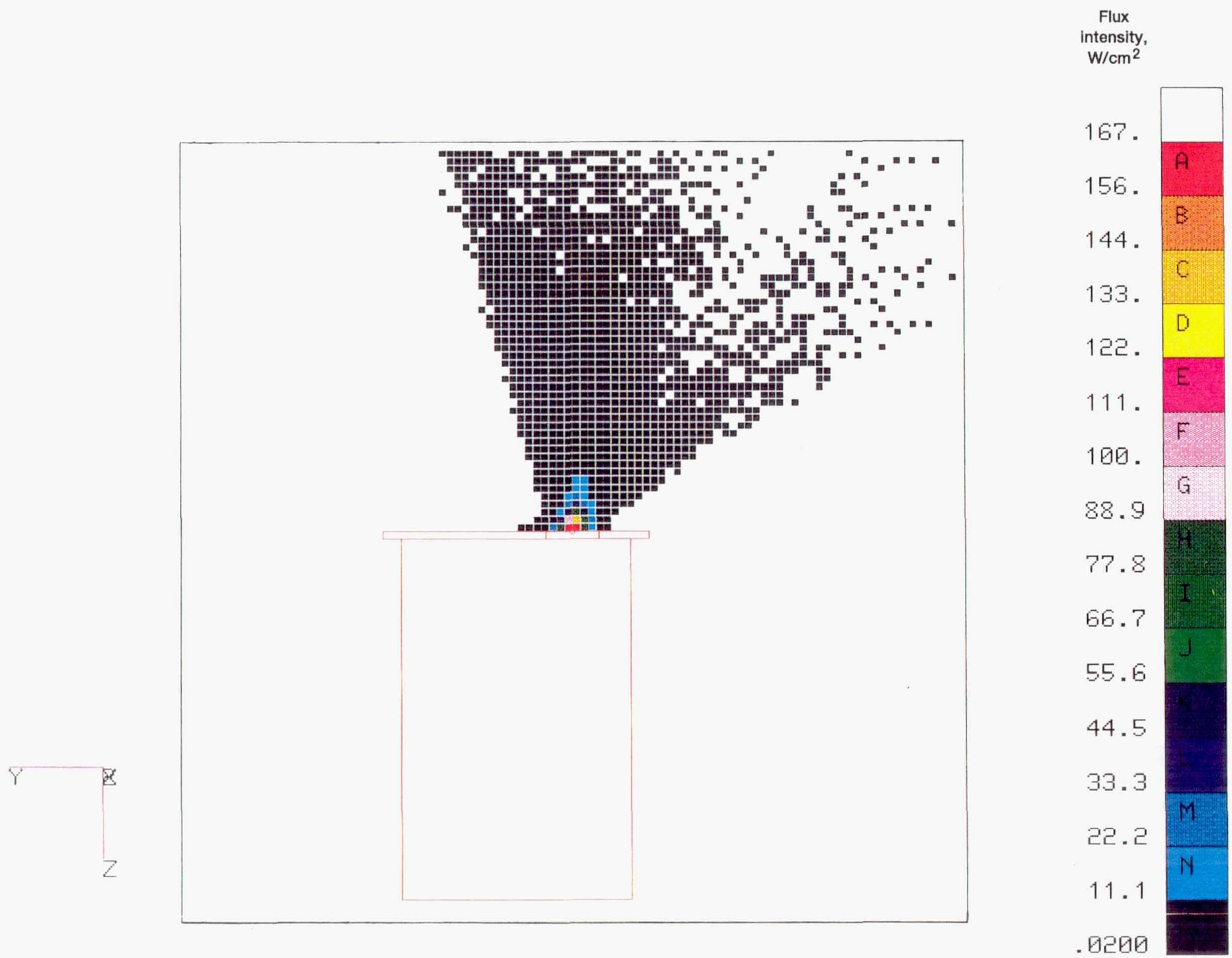

Figure 3.—Flux distribution on radiator (100-by 100-in. ^{2} area of radiator plane; alpha and beta mispoint angles, 0°).

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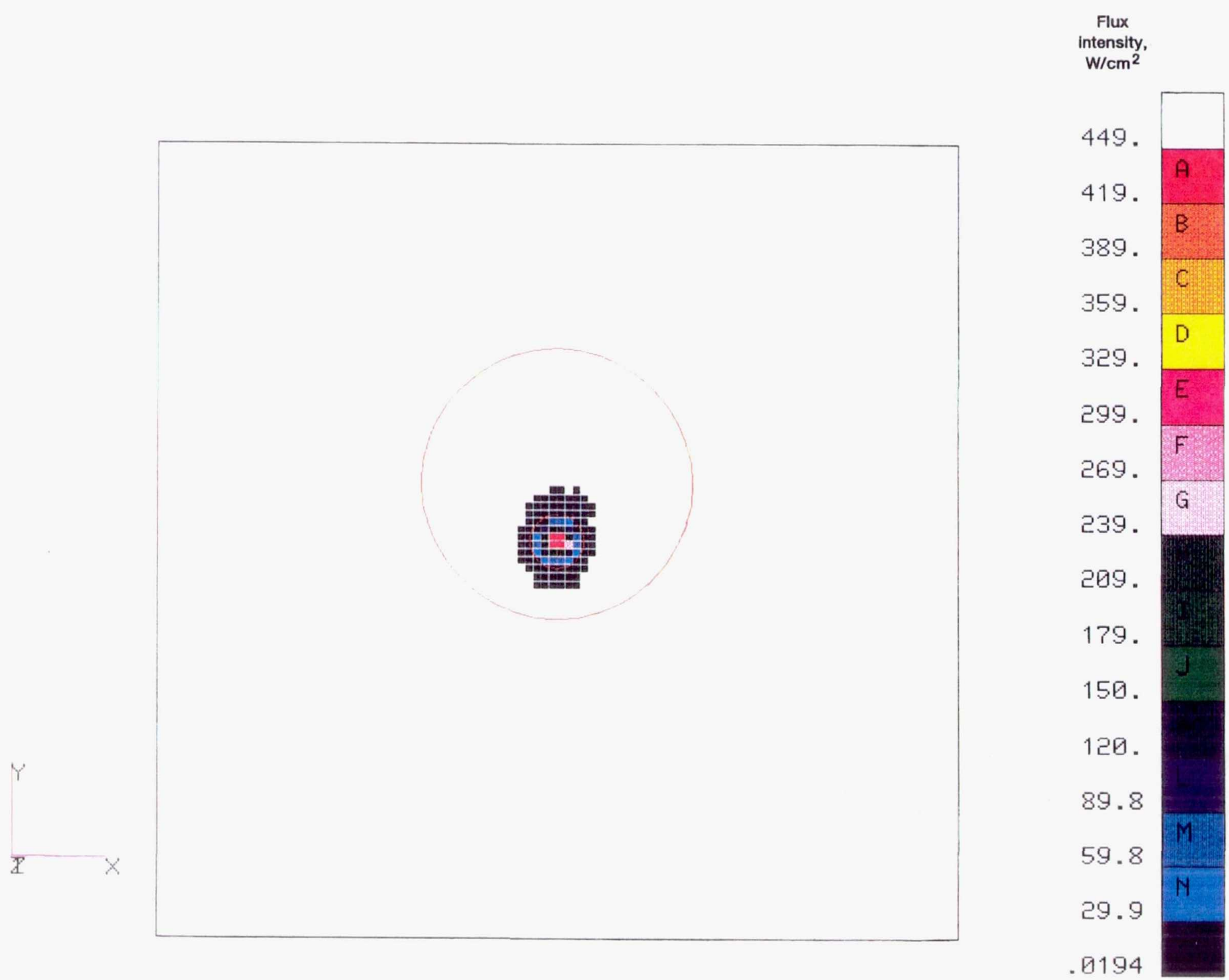

Figure 4.—Flux distribution on aperture plate (100-by 100-in. ^{2} area of aperture plane; alpha and beta mispoint angles, 0°).

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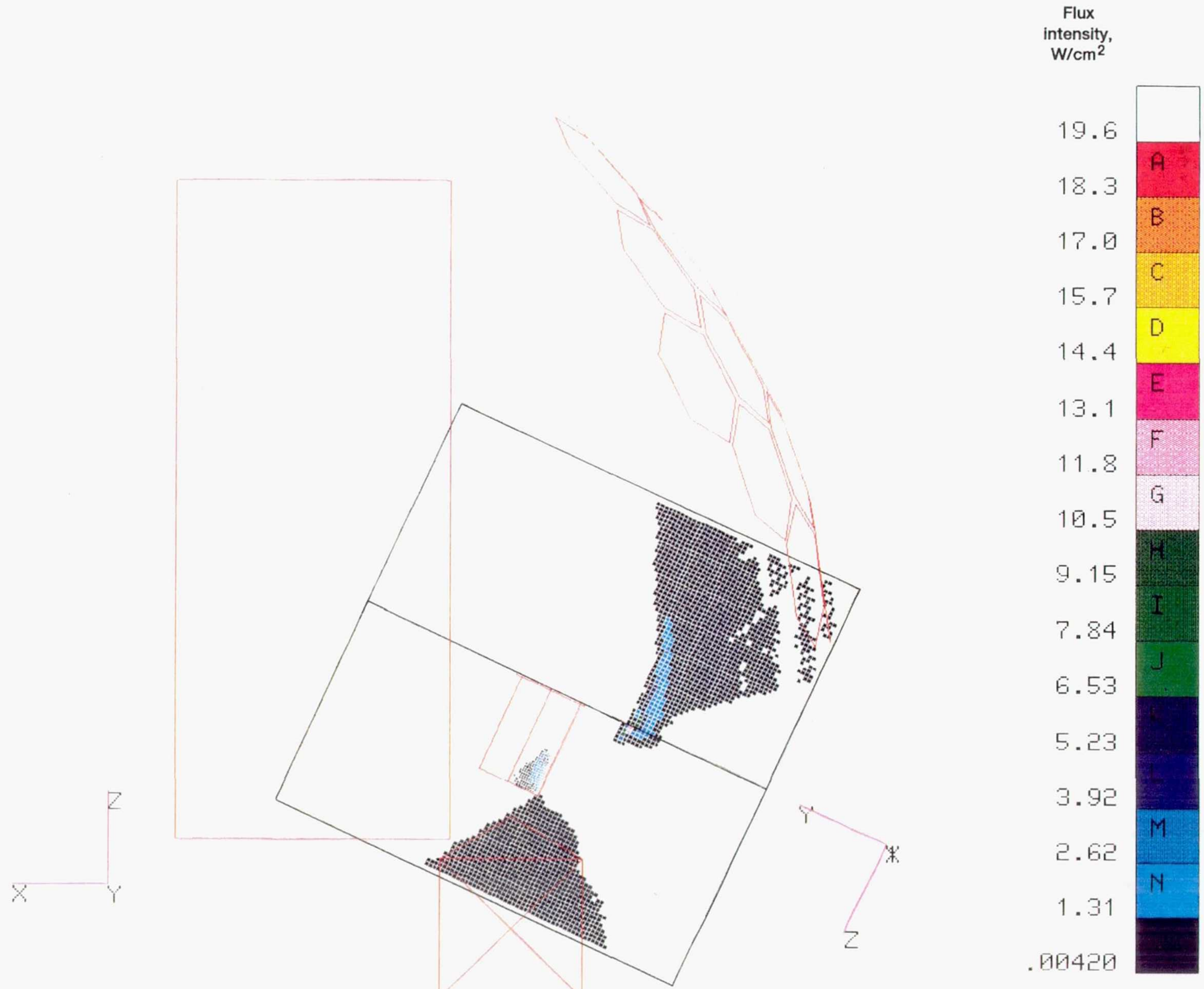

Figure 5.—Peak flux distribution on truss (500-by 500-in. ^{2} planes; alpha and beta mispoint angles, 0° and 5°, respectively).

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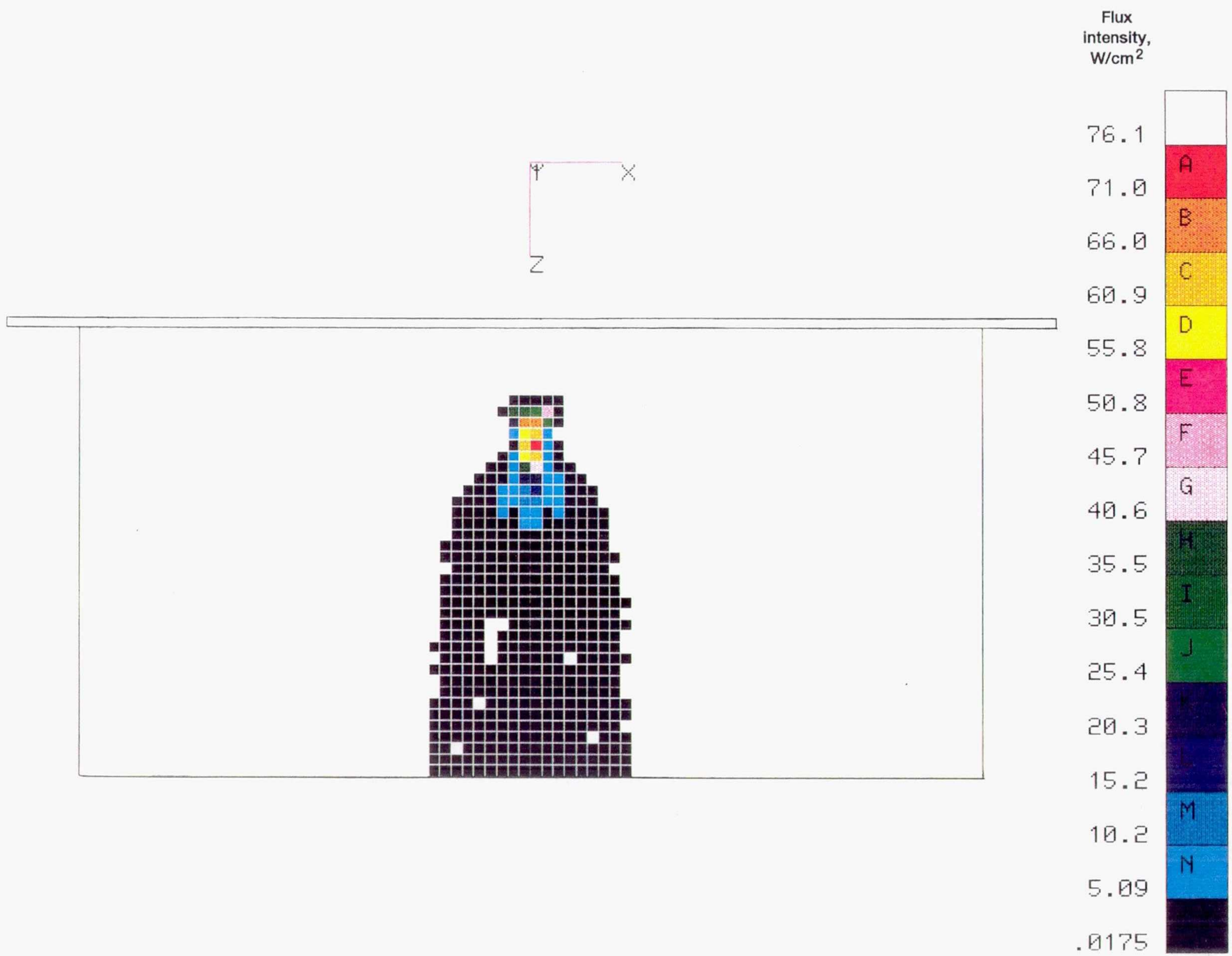

Figure 6.—Peak flux distribution on outside of receiver (alpha and beta mispoint angles, 5° and 0°, respectively).

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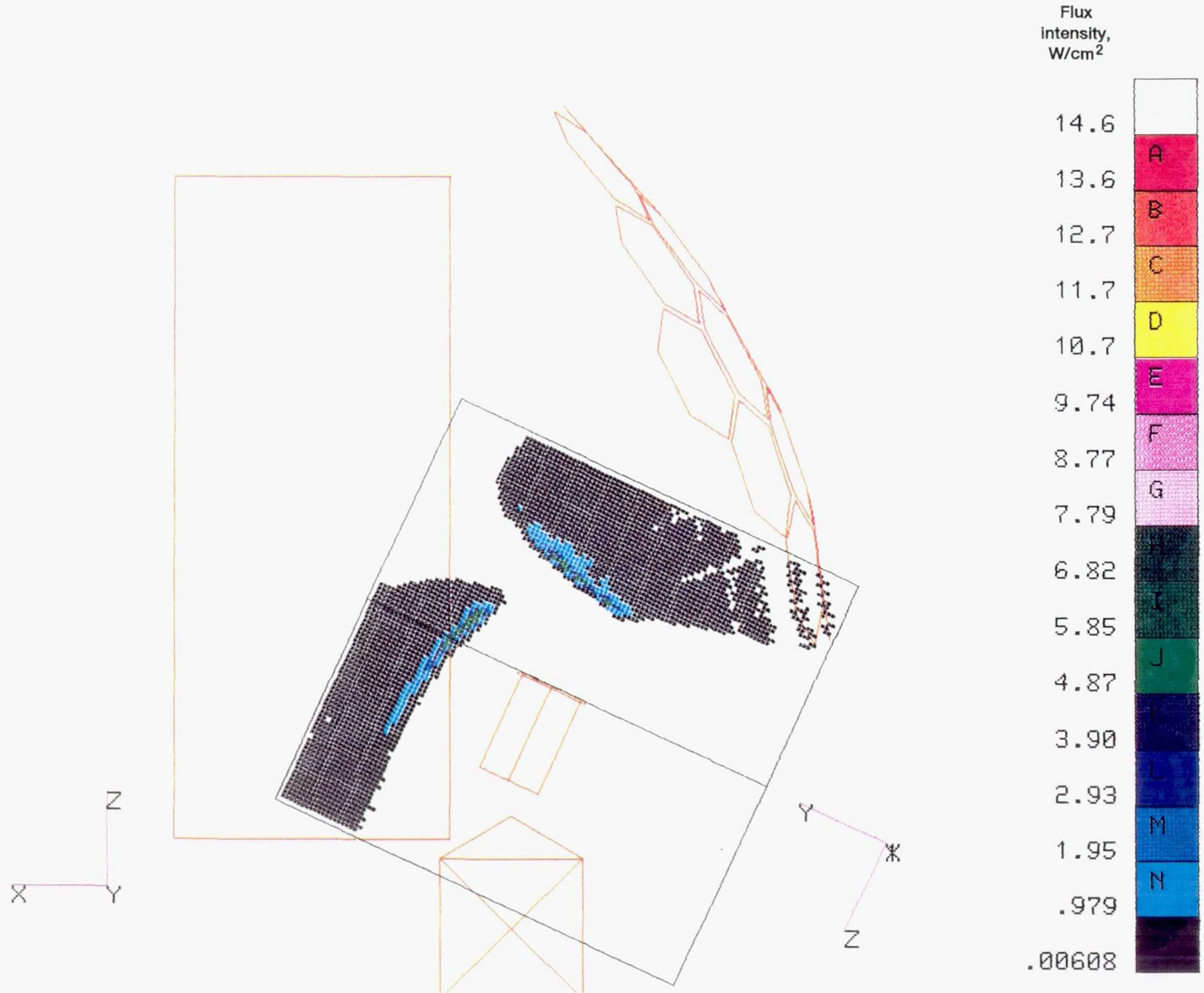

Figure 7.—Peak flux distribution on radiator (500-by 500-in. 2 area of radiator plane; alpha and beta mispoint angles, −15° and 5°, respectively).

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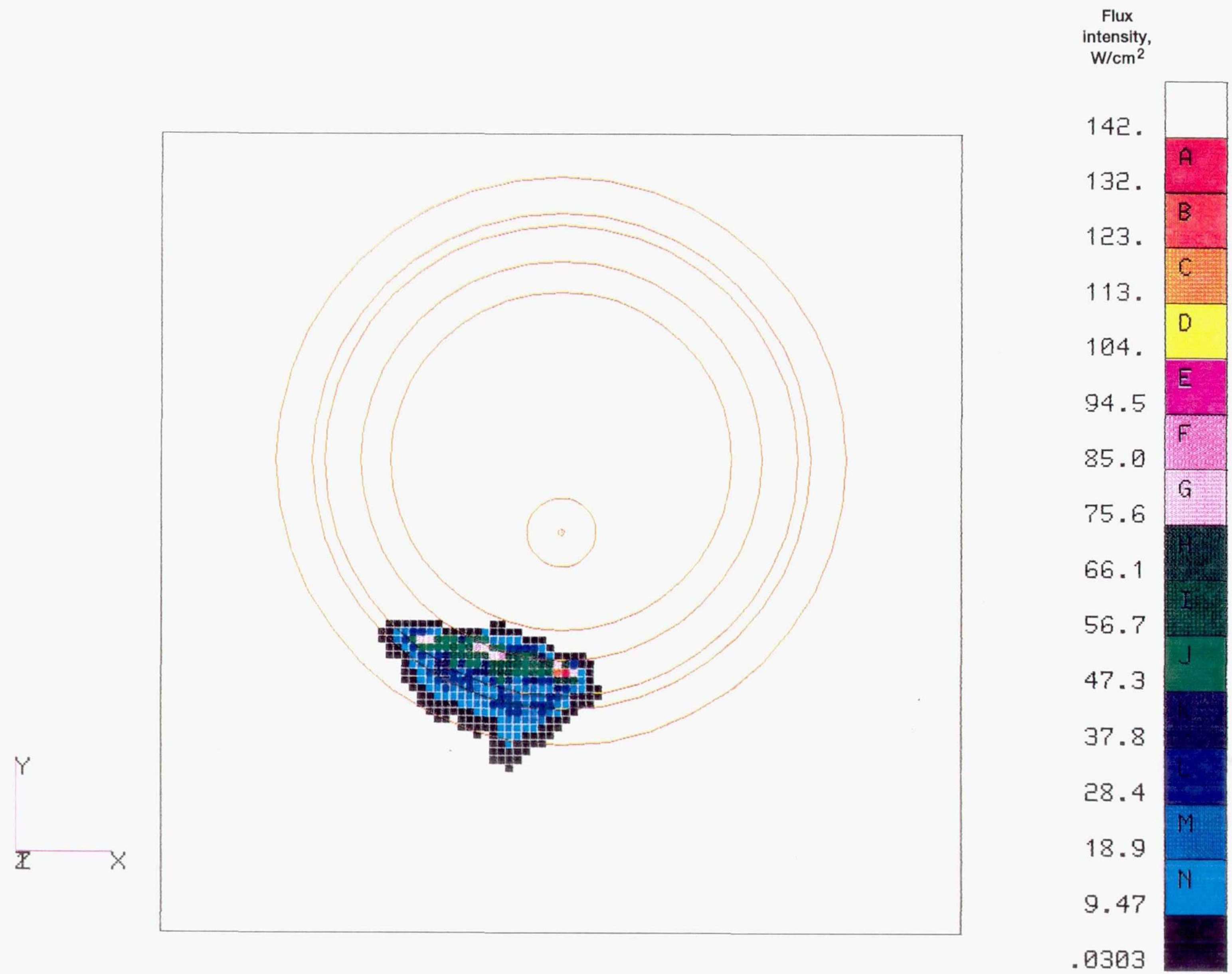

Figure 8.—Peak flux distribution on gimbal rings (200-by 200-in. ^{2} area of aperture plane; alpha and beta mispoint angles, 4° and 2°, respectively).

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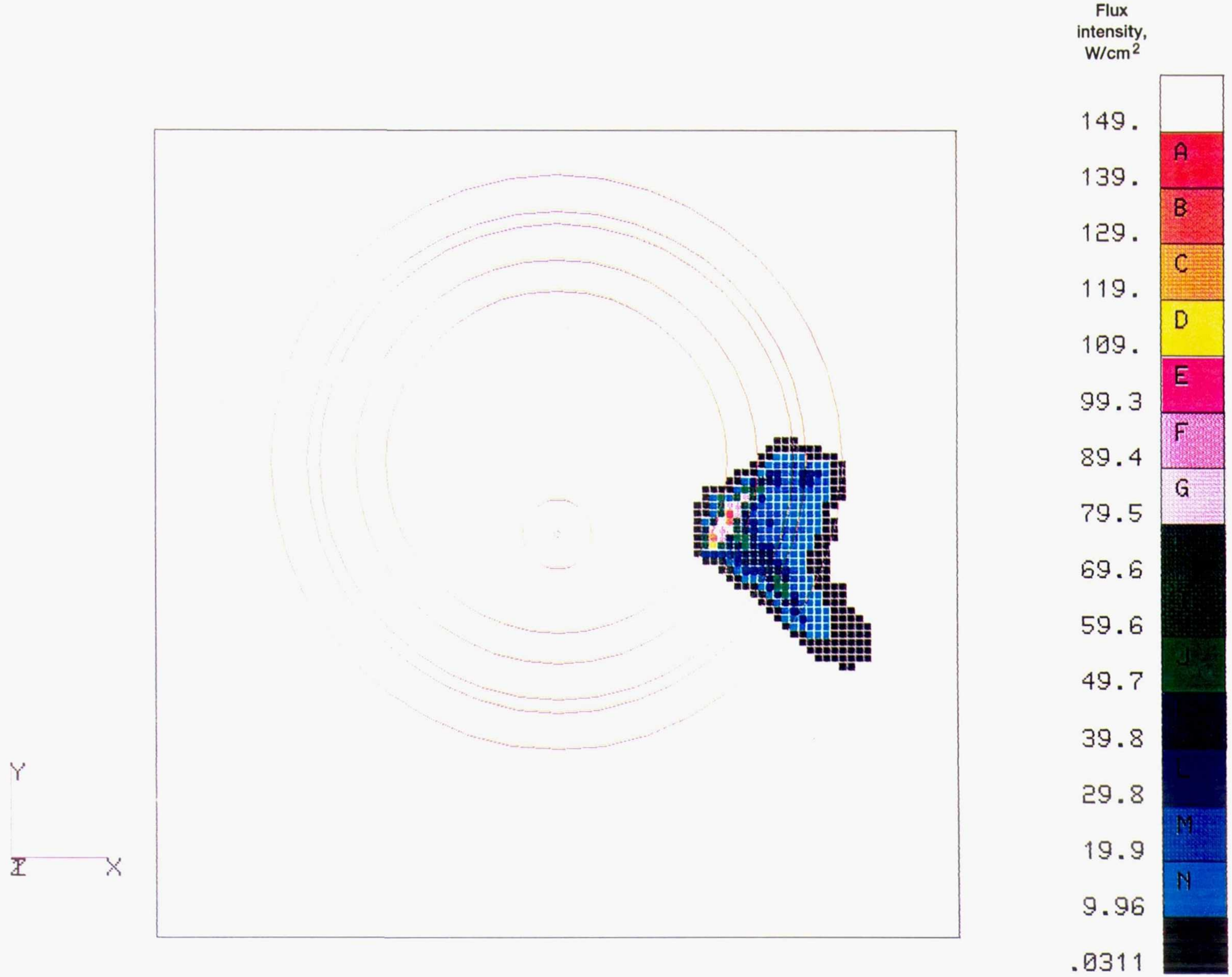

Figure 9.—Peak flux distribution on concentrator struts (200-by 200-in. ^{2} area of aperture plane; alpha and beta mispoint angles, 2° and 8°, respectively).

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13. ABSTRACT ***(Maximum 200 words)***

Mispointing of the solar dynamic (SD) concentrator designed for use on Space Station Freedom (SSF) causes the optical axis of the concentrator to be nonparallel to the incoming rays from the Sun. This causes solar flux not to be focused into the aperture hole of the receiver and may position the flux on other SSF components. A Rocketdyne analysis has determined the thermal impact of off-axis radiation due to mispointing on elements of the SD module and photovoltaic (PV) arrays. The conclusion was that flux distributions on some of the radiator components, the two-axis gimbal rings, the truss, and the PV arrays could present problems. The OFFSET computer code was used at Lewis Research Center to further investigate these flux distributions incident on components. The Lewis study included distributions for a greater range of mispoint angles than the Rocketdyne study.

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